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ON THE ORIGIN OF THE DETONATION SPIN

A. N. Voinov

/A Digest/

The phenomenon of the detonation spin, in which the flame propagates along a spiral path close to the walls of the tube, has been so contradictory that no rational explanations for its occurrence have been given until quite recently. The experiments of A. S. Sokolik and M. A. Rivin [1] and of K. I. Shchelkin [2] showed that detonation spin always occurs near the propagation limits in any gas mixture.

The theory proposed by K. I. Shchelkin [3] and developed by Zeldovich [4] gives the following explanation for spin. In very lean or rich mixtures, the reaction velocity is insufficient to cause the ignition of the mixture in the front of a plane shock wave. However, if the shock wave should have a "break," the higher temperature in such a break would induce an ignition source which would be nothing more than the "head" or "nucleus" of the spin. It follows from gas-dynamic considerations that the propagation of the break and of the associated flame zone must be quite stable and equivalent to the propagation, along a spiral path, of a special detonation wave bounded on the sides by a highly compressed gas which has not reacted. This theory offers a good explanation for the experimental results which were previously considered contradictory. However, since it attributes the initial occurrence of the break in the shock wave to accidental causes, it seems to be inadequate for the explanation of the unusual regularity with which detonation spin occurs even in tubes with the most verse cross sections.

Let us see how the initial ignition of the gas can occur when a shock wave of increasing amplitude propagates through it. We consider a shock wave propagating with velocity D (see appended figure). Behind the front the gas has a pressure P, a temperature T, and a flow velocity W which exceeds the sonic velocity. The slightest irregularities in the walls produce local discontinuities of flow which extend out toward the center of the flow as Mach waves inclined at an angle $\sin\alpha = c/w$ to the axis of the flow. A network of these lines in a steady flow has the well-known form shown in the left part

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of the appended figure, where the disturbances envelope the entire cross section of the tube. Obviously the amplitude of the Mach waves must be greater near the walls than at the center of the flow. Directly behind the shock wave the Mach lines do not have time to envelop the entire cross section and the picture must be as shown on the right side of the appended figure, where the broken lines are sound waves and the solid lines are Mach lines of finite amplitude.

The pressure and temperature are slightly higher behind each Mach line than ahead of it. This means that we have an annular layer, close to the walls, in which temperature and pressure are higher (than in the rest of the cross section) due to the dynamic friction against the walls. It is obvious that the flame originated by the initial source of autoignition must first propagate through the same annular layer since every portion of this layer is close to the ignition point. The flame will propagate in the annular layer with an extremely high velocity and will produce a transverse shock wave which will remain associated with the flame front. The transverse or rotating shock wave will continue to propagate in the annular gas layers which are not quite ready for autoignition and will catch up with the main shock wave thereby producing a break in it. This will assure a completely stable propagation of the detonation spin as shown theoretically by K. I. Shchelkin and Ya. B. Zeldovich.

Experiments show that often, in the initial period after its origin, detonation has a spin characteristic which later disappears. This readily follows from our concept, according to which any detonation caused by the self-acceleration of the flame must initially be of the spin type; however, if the mixture is remote from the detonation limits, the spin mechanism can last only a very short time. It seems possible that even near the detonation limits the reaction in the transverse shock wave will develop so slowly that the flame propagating along the spiral path will never catch up with the main shock wave. In spite of this, the detonation spin may be quite stable and its pitch will be determined by the relation between the velocity of the main shock wave and the velocity of the transverse wave.

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/Appended figure follows/

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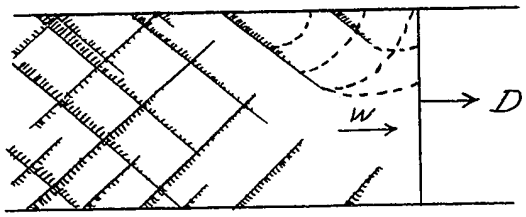

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